Research opportunities with DUNE and SNO+

DEEP UNDERGROUND NEUTRINO EXPERIMENT

9th mini-school on Particle and Astroparticle Physics

6 February 2024

LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

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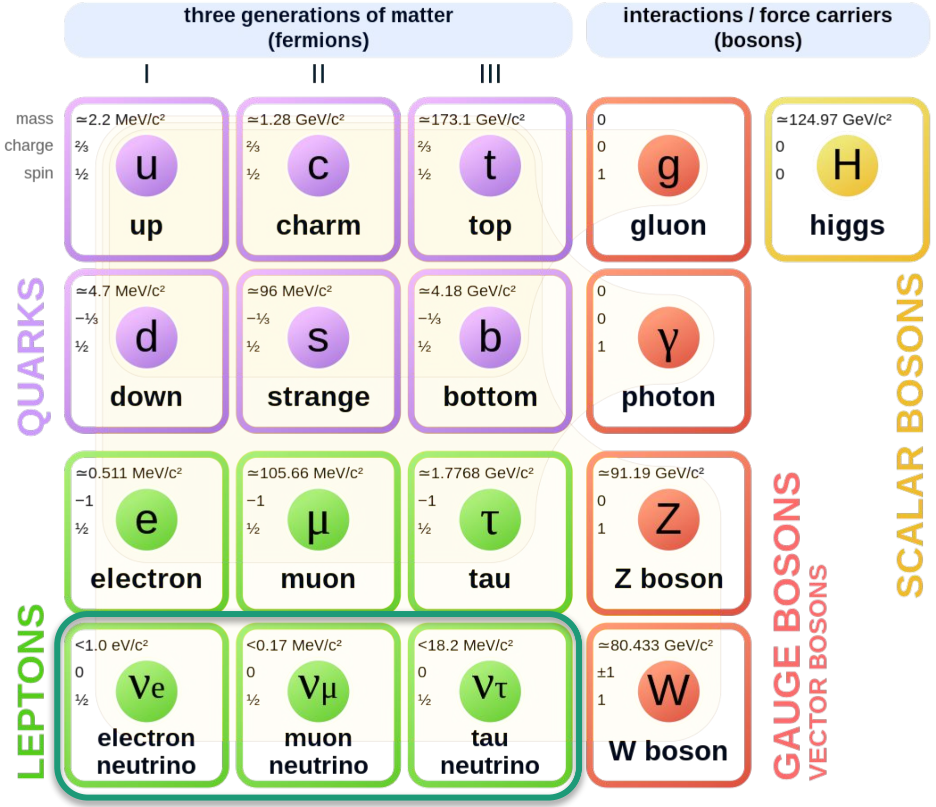
What we know about neutrinos

- They oscillate between their three flavours (ν_μ, ν_e and ν_τ) as they propagate through space-time.
  - This implies they have mass!
    - But **not** in original Standard Model formulation.

- We **know** the absolute difference between their masses.

- We **know** mixing between neutrino flavours is **much larger** than mixing between quarks.

More details in last Monday's lecture.

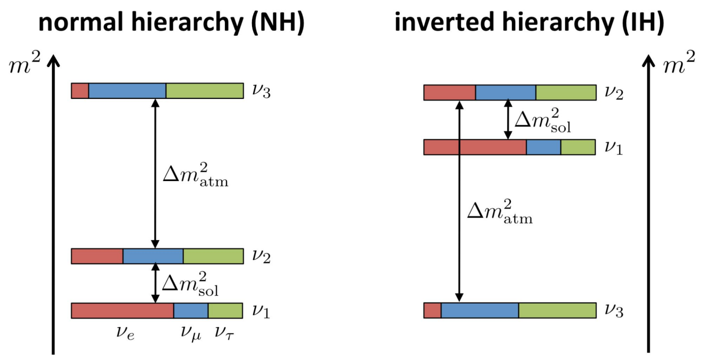


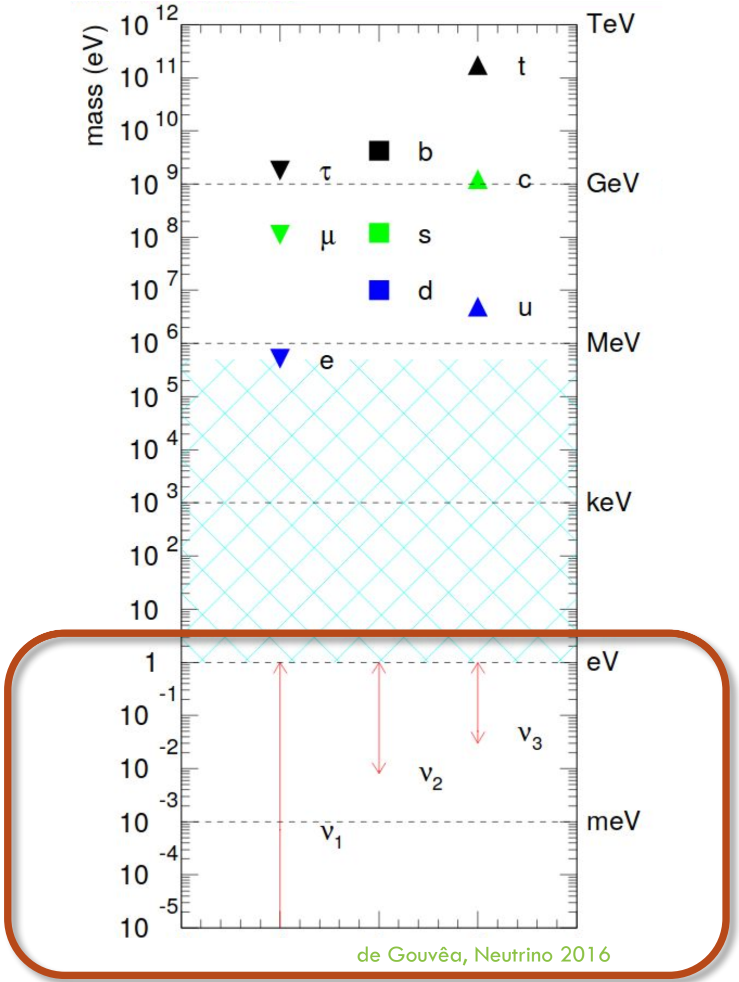
What we don't (yet) know

- What is the **lightest** of the neutrino masses?
- Are there **symmetries** in the neutrino mixing pattern?
- Do **neutrinos** and **antineutrinos** oscillate with **equal probabilities**?

- Are neutrinos **their own antiparticles** (Majorana vs Dirac)?
- What is the **absolute mass scale** of neutrinos?

- Answering the above will lead to a deeper understanding of:
  - **Matter-antimatter (a)symmetry** in the Universe.
  - The nature of **mass**.





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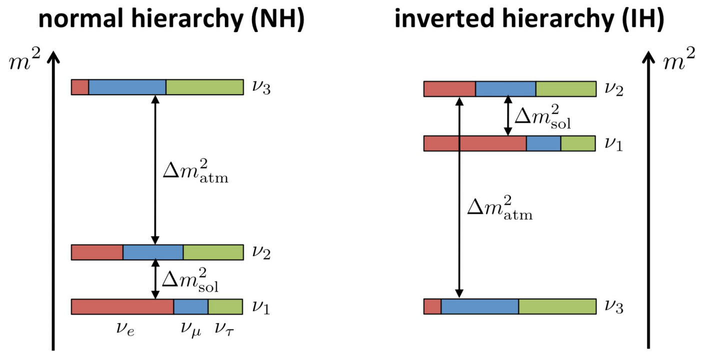


SNO+

The SNO+ Detector

- Located at a depth of 2 km
  - 5900 metre water equivalent
  - ~63 cosmic-ray muons / day
    - O(100)/m^2/s at the surface

As of April 2022 fully filled and taking data

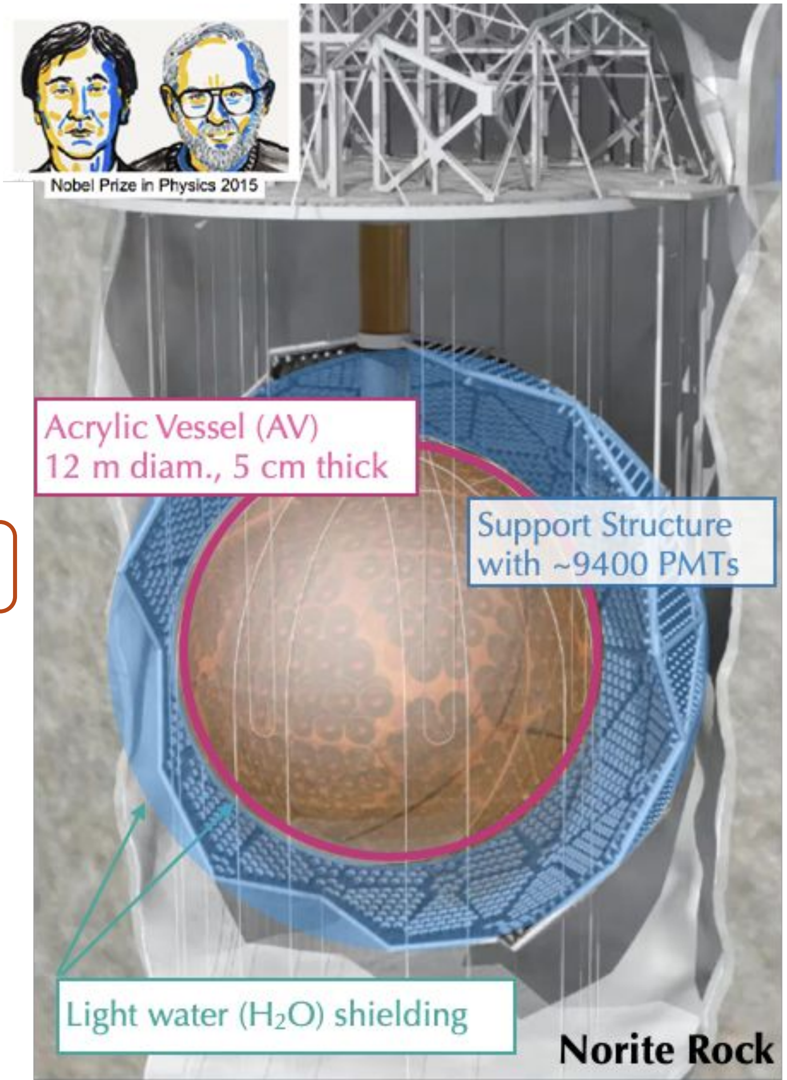
905 tonnes of ultra-pure water

↓

780 tonnes of Liquid Scintillator

↓

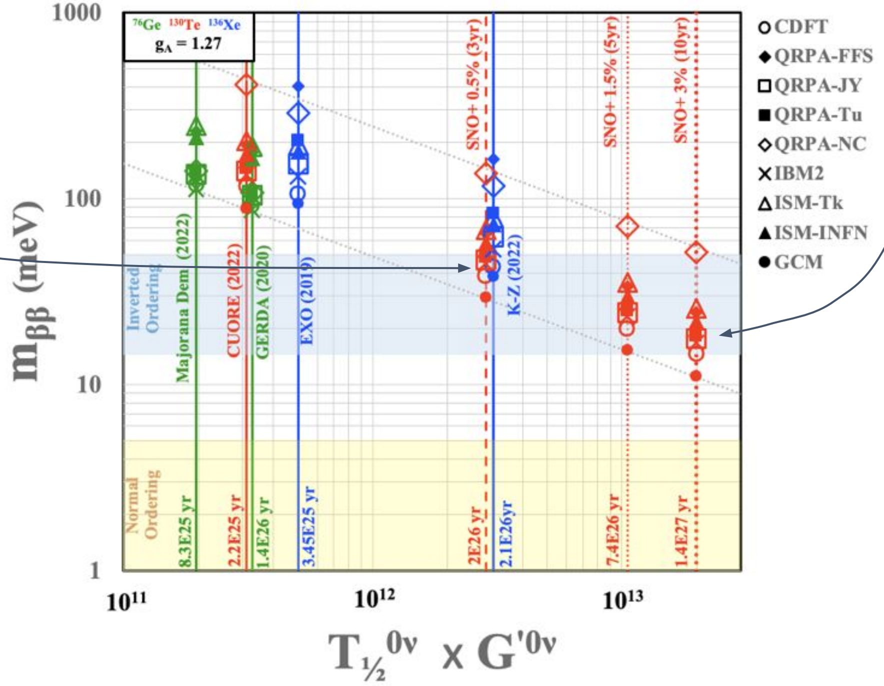
+ 3.9 tonnes of natural Tellurium

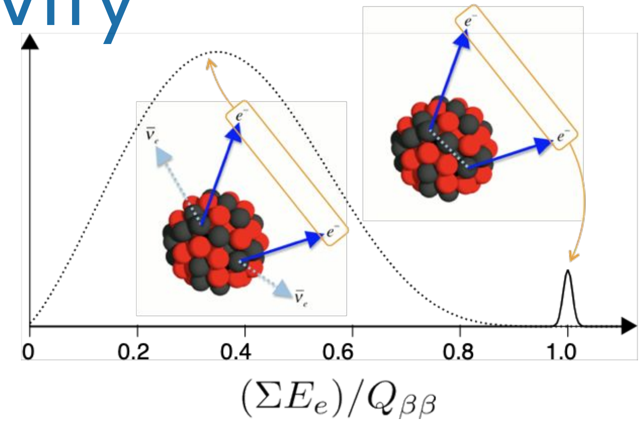


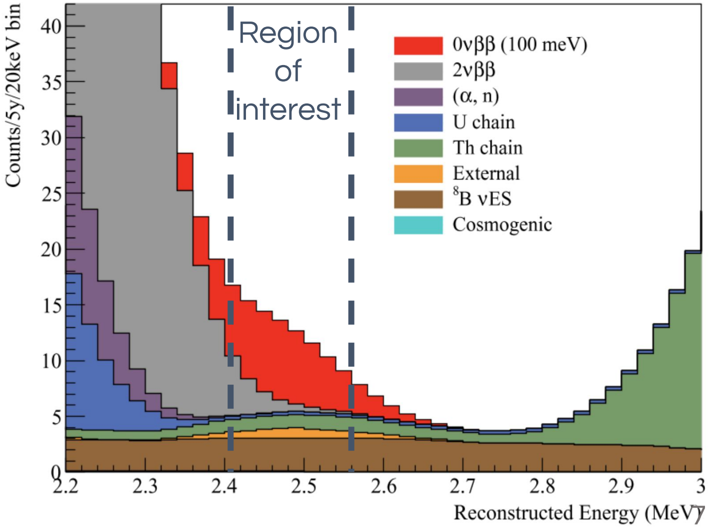
Double-beta decay sensitivity

Reminder:
Neutrinoless double-beta decay occurs only if neutrinos are their own antiparticles!

- Depending on nuclear models, SNO+ can have leading sensitivity
- Possible to increase Tellurium loading from 0.5 to 3% and do even better!

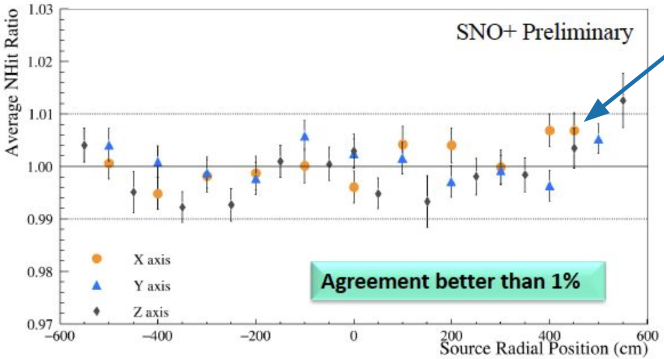






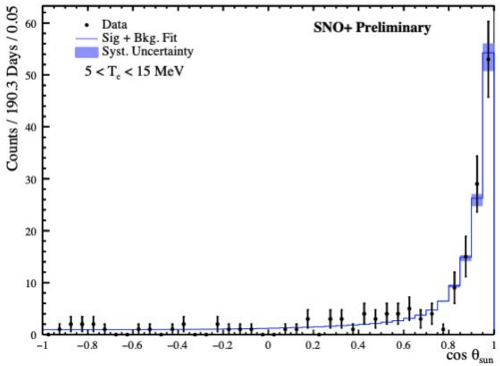
SNO+ Water Phase (2017-2019)

Ratio between data and MC

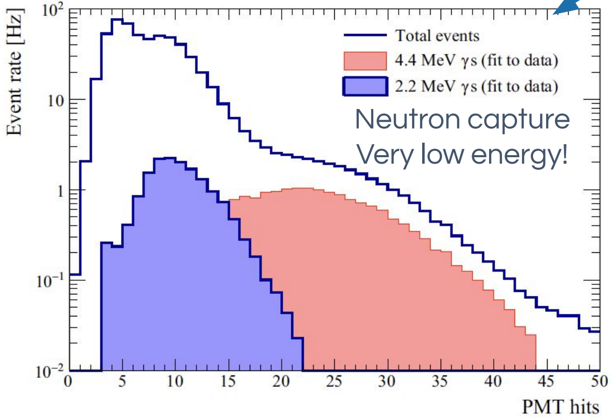


Extensive calibrations with optical and radioactive sources. Improvement over SNO.

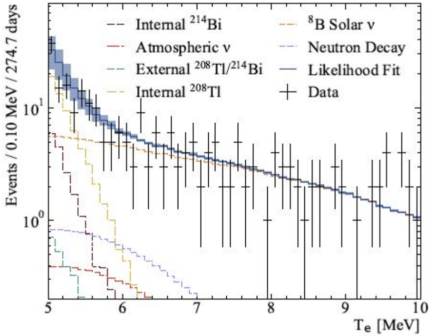
Solar neutrino data



Best neutron response of any water Cherenkov detector
→ Crucial for antineutrino identification!



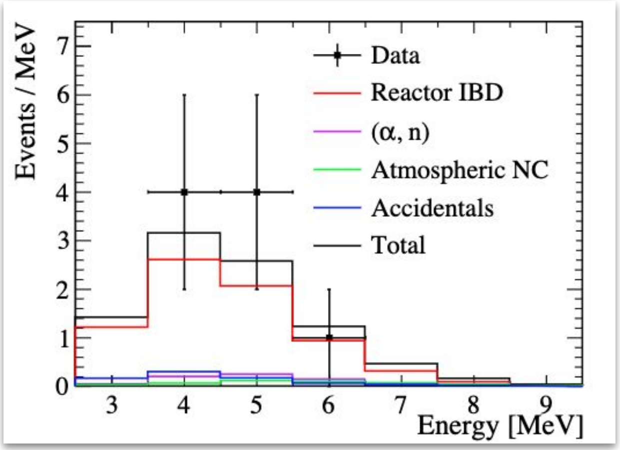
Improved search for invisible modes of nucleon decay in water



Decay Mode	Partial Lifetime Limit	Existing Limits
n	9.0×10^{29} y	5.8×10^{29} y [5]
p	9.6×10^{29} y	3.6×10^{29} y [6]
pp	1.1×10^{29} y	4.7×10^{28} y [6]
np	6.0×10^{28} y	2.6×10^{28} y [6]
nn	1.5×10^{28} y	1.4×10^{30} y [5]

Best limit for all channels!

SNO+ Water Phase (2017-2019)



First evidence of reactor antineutrinos in a Cherenkov detector!

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APRIL 11, 2023 FEATURE Editors' notes

The SNO+ collaboration gathers the first evidence of antineutrinos in a water Cherenkov detector

by Ingrid Fadelli , Phys.org

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physicsworld

accelerators and detectors

ACCELERATORS AND DETECTORS | RESEARCH UPDATE

Reactor antineutrinos detected in pure water in an experimental first

28 Mar 2023

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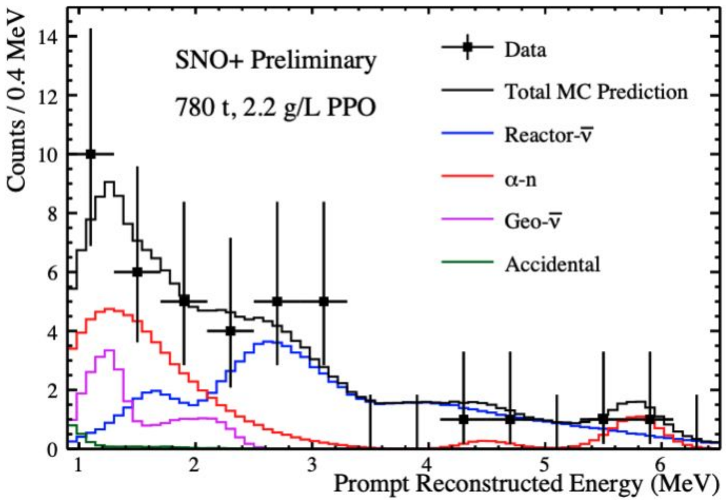
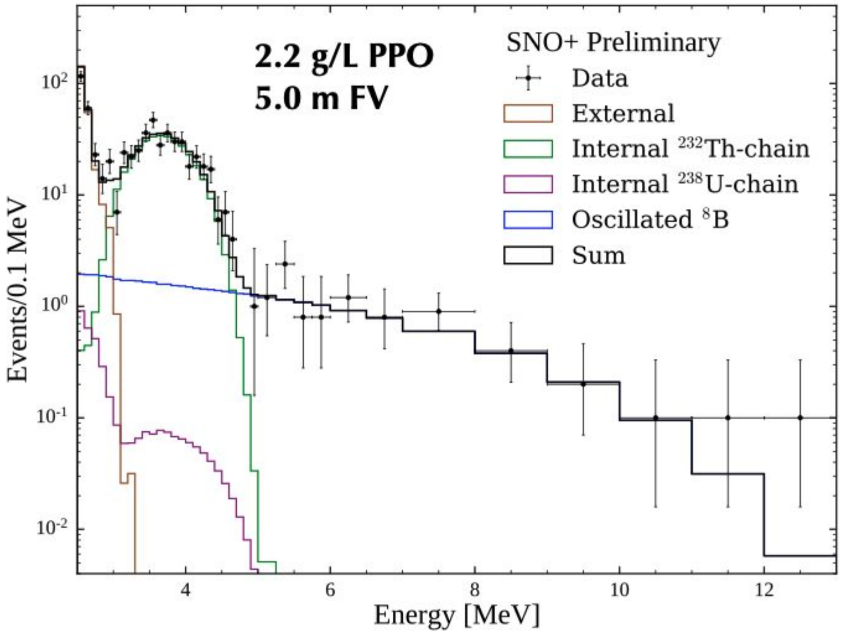
Evidence of Antineutrinos from Distant Reactors Using Pure Water at SNO+

A. Allega *et al.* (The SNO+ Collaboration)
Phys. Rev. Lett. **130**, 091801 – Published 1 March 2023

SNO+ Scintillator Phase (2020+2022-now)

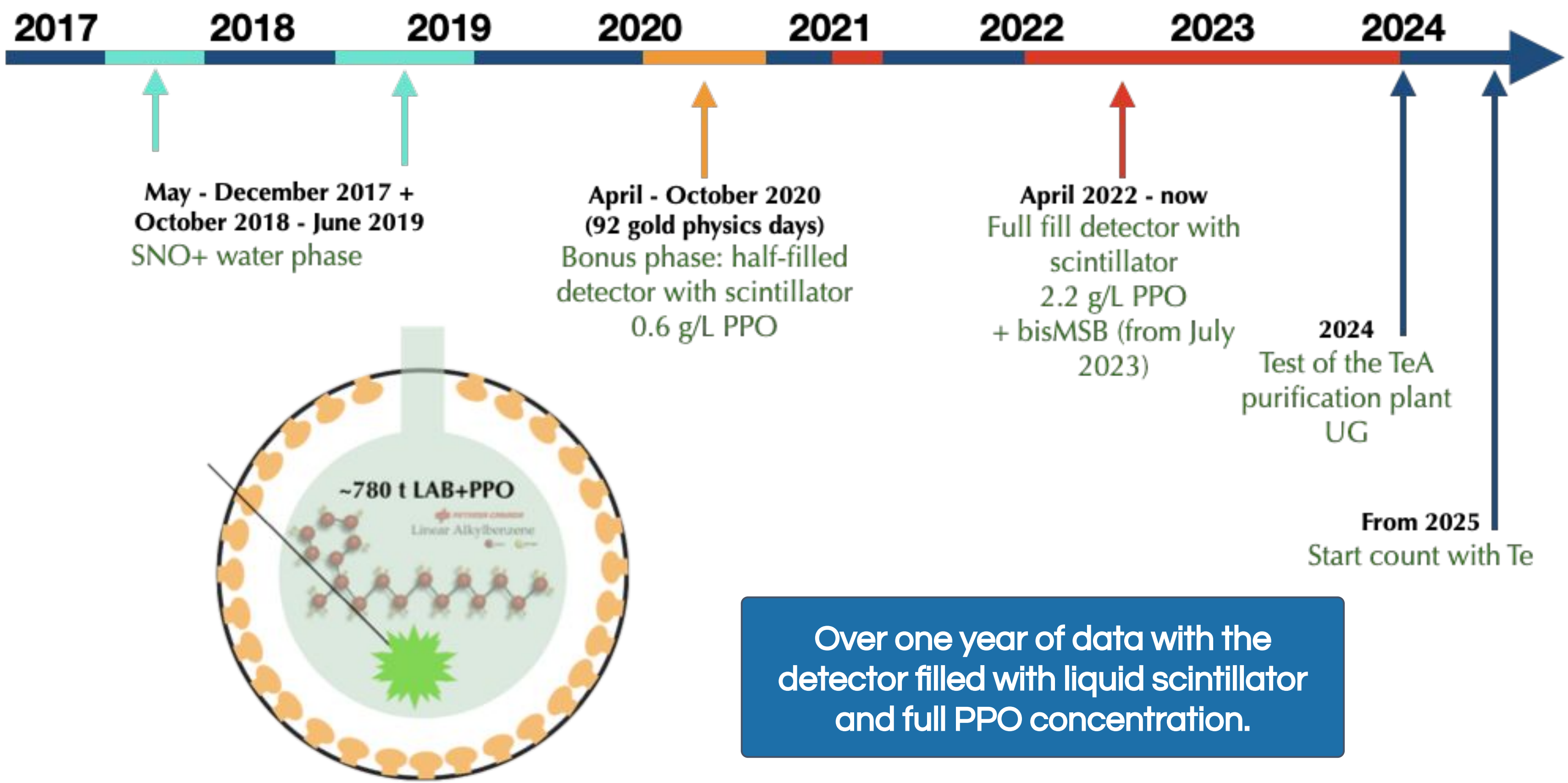


Reactor antineutrino measurement in scintillator



Solar neutrino measurement in scintillator

SNO+ timeline

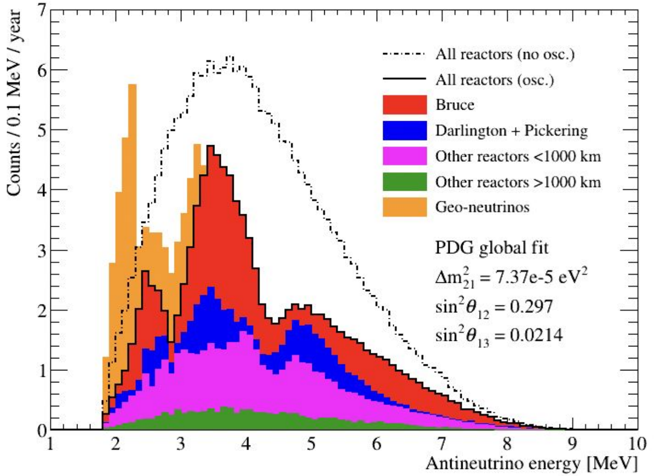


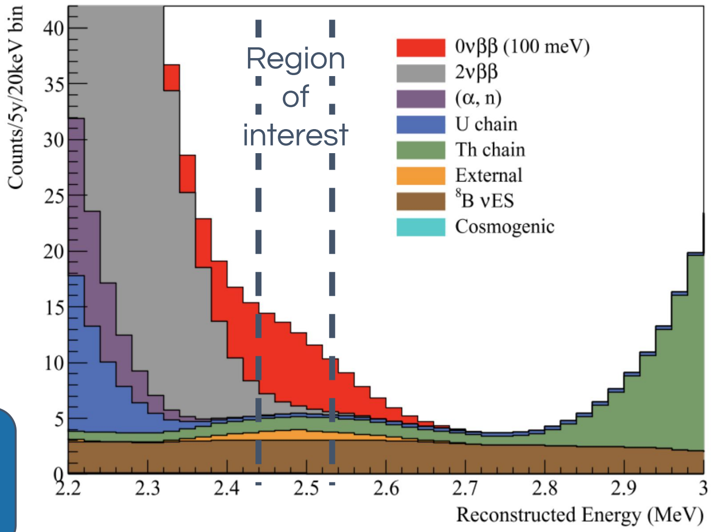
Over one year of data with the detector filled with liquid scintillator and full PPO concentration.

SNO+ student projects: with scintillator data

- **Measure reactor antineutrino oscillations and its backgrounds**
  - Coincidence tagging helps reduce backgrounds
  - Help clarify current ambiguity between solar experiments and the KamLAND experiment.
  - Possibly detect the first geo-neutrinos in North America?

- Fully understand the **radioactive background sources** in the region of interest for neutrinoless double-beta decay.
  - Background tagging techniques
    - U, Th and (alpha,n) decays/reactions in the current scintillator data.
    - Identify any other background source that might fall in that region.





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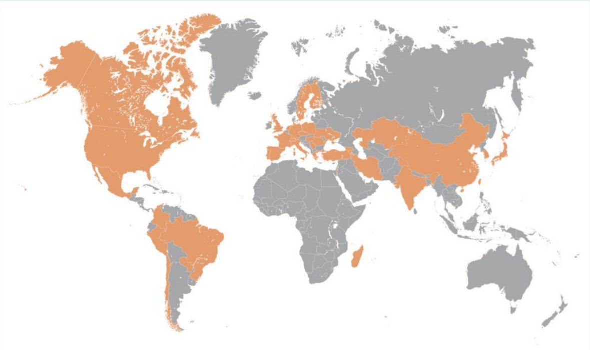
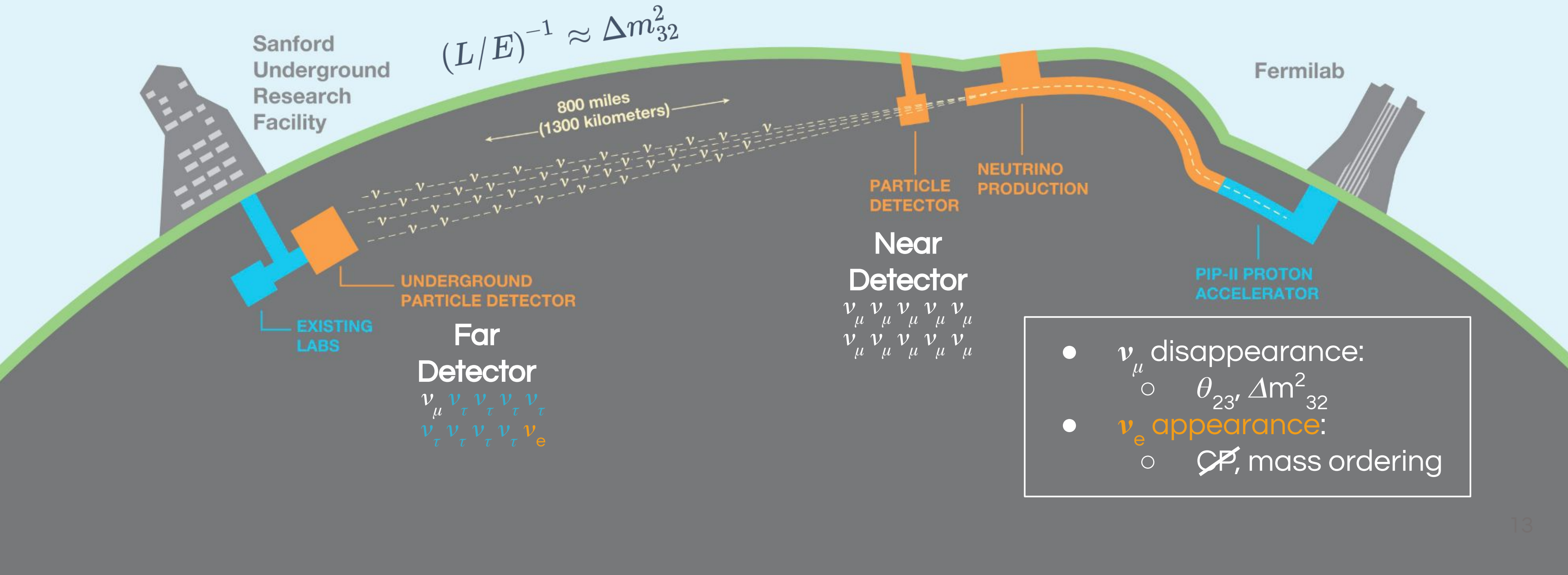
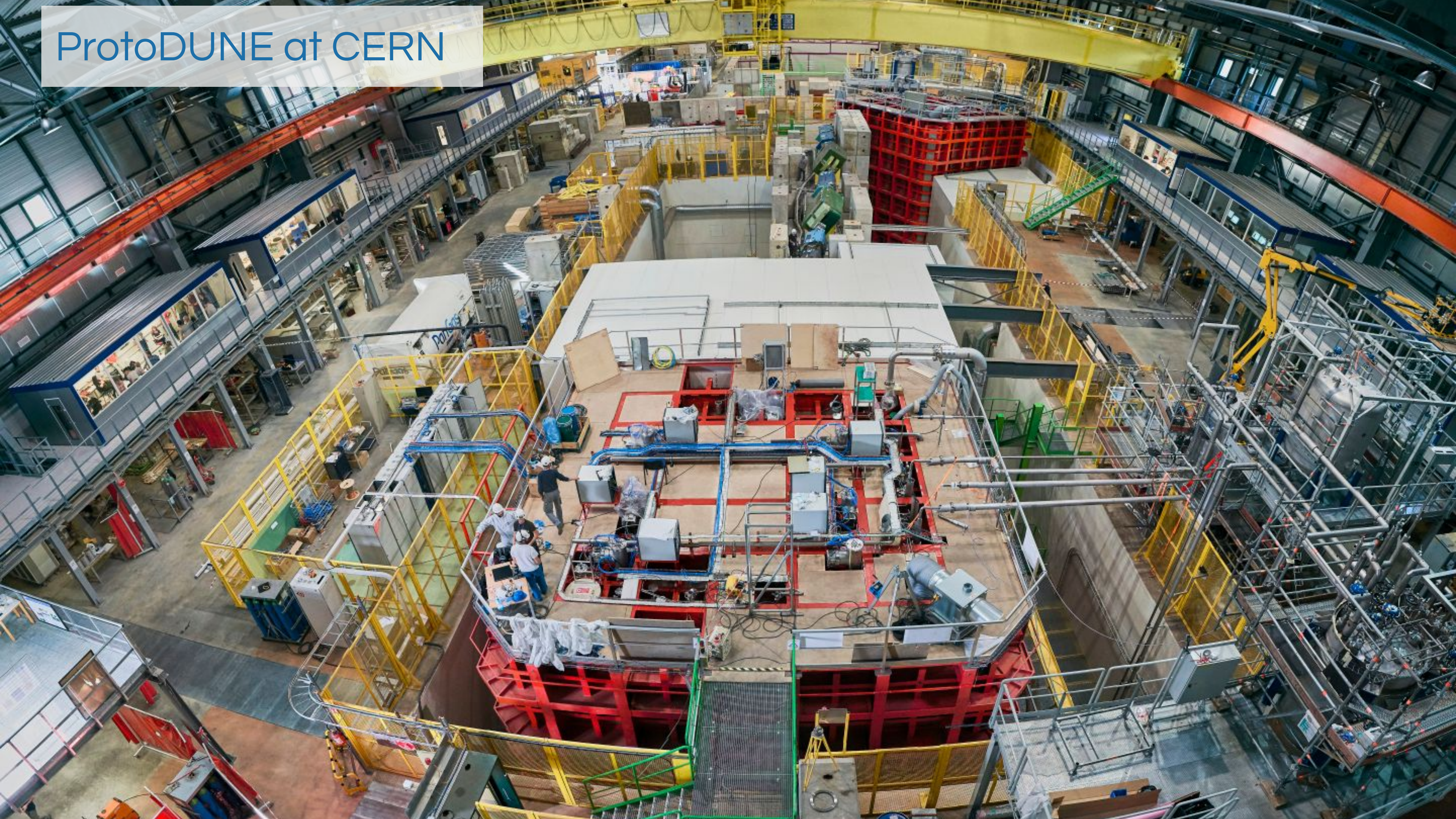




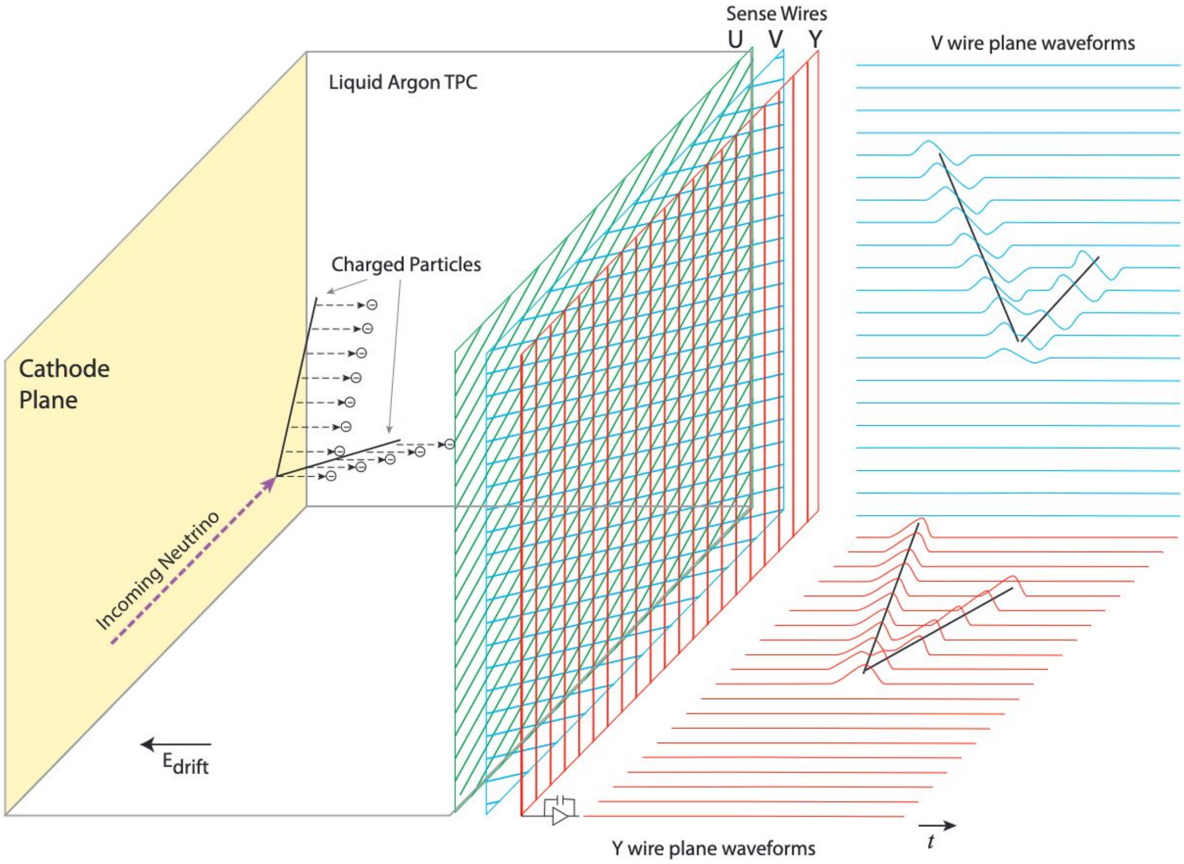
- ν_μ disappearance:
  - θ_{23}, Δm^2_{32}
- ν_e appearance:
  - ~~CP~~, mass ordering

ProtoDUNE at CERN

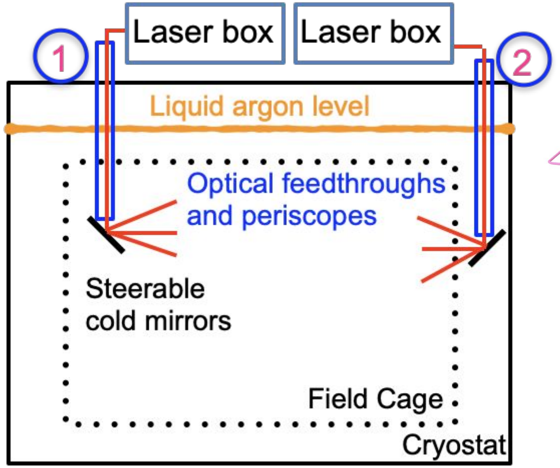


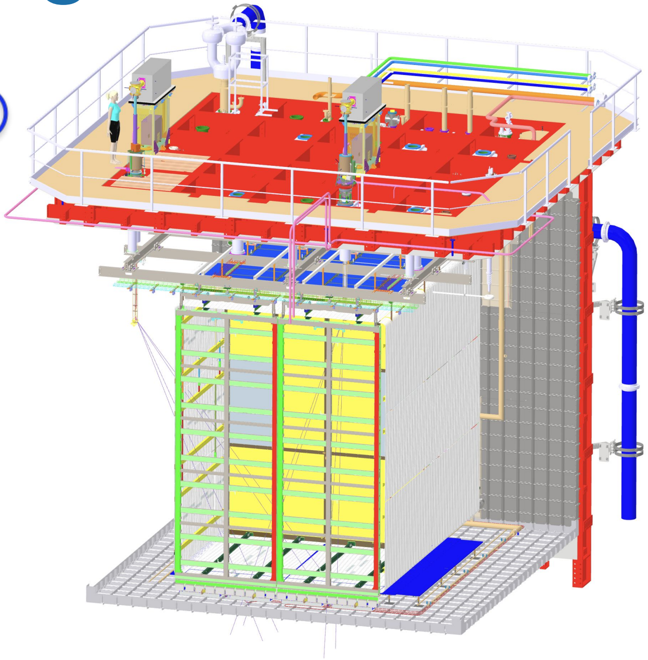
Liquid-argon time-projection chamber

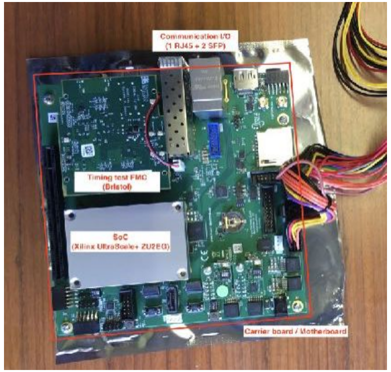
Advanced detector technology to meet DUNE's high-precision requirements.

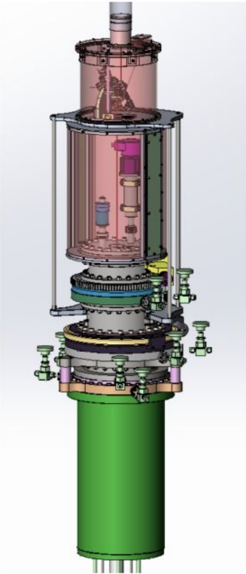


Calibrating LArTPCs with lasers



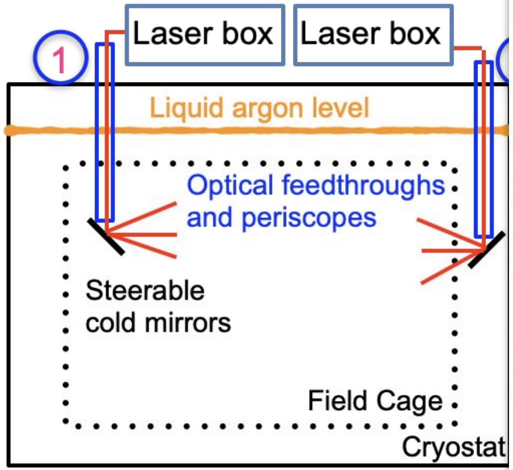


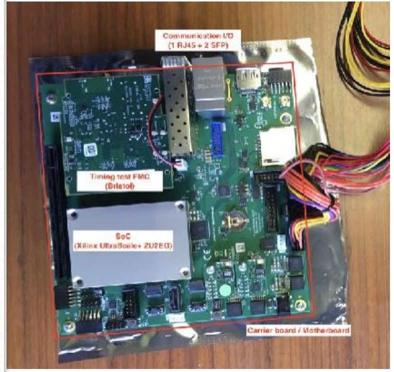


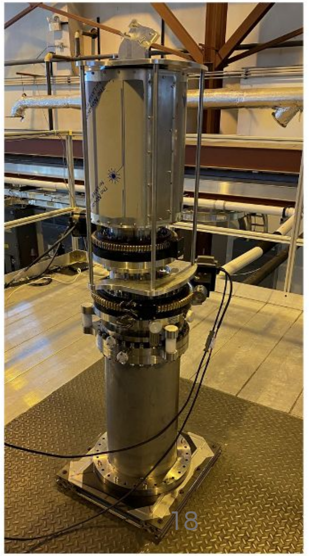


- Precise measurements need well calibrated detectors!
- Two periscopes with lasers to be tested in ProtoDUNE.
  - Designed and built by LIP and Los Alamos National Laboratory.

Calibrat sers







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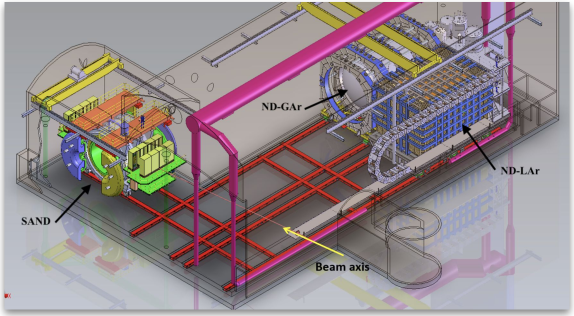
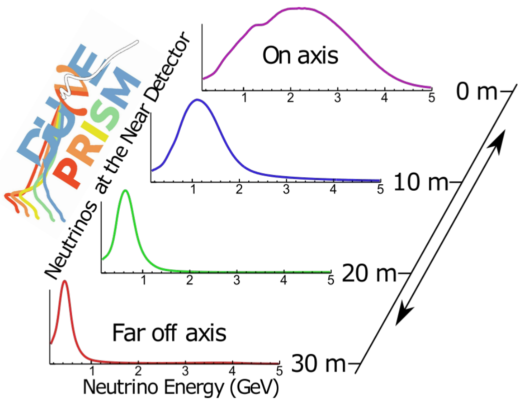
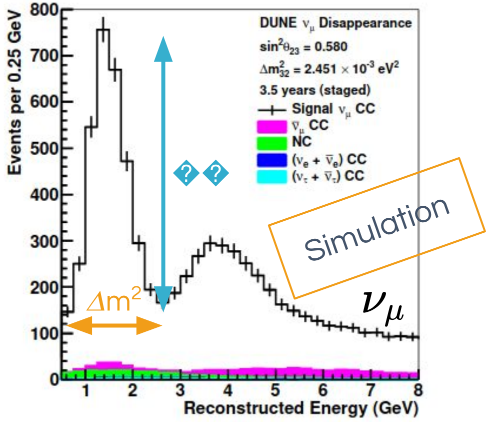
Oscillation measurements

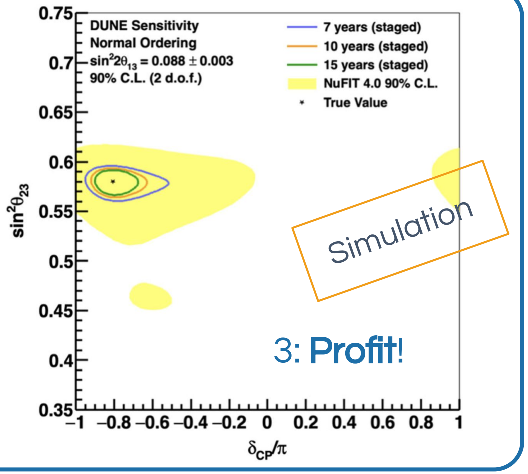




1: Take data with **moveable** near detector.



2: Compare to **far** detector data.



3: **Profit!**

- DUNE's near detector will be **on rails**!
  - Innovative strategy to significantly improve the precision of the experiment.
- New analysis methods need to be developed to fully exploit this capability of the experiment.

DUNE student projects

- **Calibration laser** simulation and data analysis [Lisboa/Coimbra]
  - Model the ionization of liquid argon by laser beams.
  - Develop analysis methods to measure the detector performance.
    - Electron lifetime, recombination, ...
- **Calibration laser** electronics, control and data acquisition [Coimbra]
  - Interface with DUNE data acquisition, automatize calibration data taking, provide precise alignment data.
- **Bismuth-207 source** at ProtoDUNE and other TPCs [Lisboa]
  - Simulate the response and analyse the data of ProtoDUNE and other TPCs with a Bi-207 source to measure electron lifetime, diffusion, stability
- **Data-driven analysis** with DUNE-PRISM [Lisboa]
  - Develop novel analysis methods for data-driven constraints on neutrino mixing parameters using DUNE simulation.
  - Explore machine learning approaches to take into account near and far detector responses.

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